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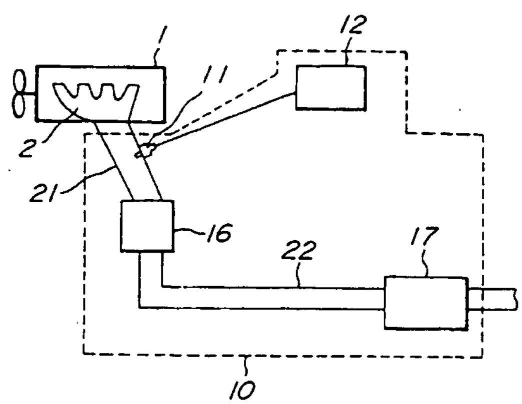
(54) Exhaust gas purifying apparatus.

(57) In an exhaust gas purifying apparatus including first (16) and second (17) exhaust converters composed of a honeycomb catalytic substrate, arranged in sequence from an exhaust manifold towards downstream exhaust gas flow of an engine (1), wherein the catalytic substrate of the first converter (16) has a heat capacity of not exceeding 0.5 J/K per 1 cm^3 in temperatures ranging from room temperature up to 300°C, and the catalytic substrate of the second converter (17) has a geometric surface area of at least 25 cm^2/cm^3. The first converter (16) purifies exhaust gas immediately after starting up and before completion of warming up of the engine (1), and the second converter (17) further purifies noxious contents still remaining as being beyond capacity of the first converter (16).

FIG. 1



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Background of the Invention

1. Field of the Invention

The present invention relates to exhaust gas purifying apparatuses for internal combustion engines (hereinafter referred to as "engines") to be used in automobiles or the like.

2. Description of the Prior Art

Regulations for exhaust gas of automobiles are becoming stricter year by year. Particularly, it is becoming more and more severely requested to decrease noxious contents in exhaust gas, such as carbon monoxide CO, hydrocarbons HC, nitrogen oxides NO_x or the like, by purifying the exhaust gas discharged immediately after starting up and before completion of warming up of engines. As a countermeasure therefor, there has been known an exhaust gas purifying apparatus to be mounted on the exhaust port of the engine, which comprises a first exhaust converter having a small capacity and a second exhaust converter having a large capacity, for converting the noxious contents into innoxious components. In such an exhaust gas purifying apparatus, the noxious contents are decreased by the first exhaust converter wherein a high temperature is readily attained and thereby a catalyst is rapidly activated, mainly immediately after starting up and before completion of warming up of the engine and then by the second exhaust converter having a larger capacity after the warming up of the engine has been completed. Among these exhaust gas purifying apparatuses, some have been so designed as to feed air at an appropriate feed rate into exhaust gas to improve an exhaust gas purification efficiency.

However, in the above-mentioned exhaust gas purifying apparatus there has been posed a problem such that since the first exhaust converter comprises a catalytic substrate having a heat capacity not small enough to sufficiently activate the catalyst while the engine is under the condition between immediately after starting up and before completion of warming up, a good exhaust gas purification efficiency cannot be obtained. In this specification, the term "heat capacity" is meant by a heat capacity of a catalytic substrate including exhaust flow passages formed therein (hereinafter, the exhaust flow passage is referred to as "cell").

Summary of the Invention

The present invention which has been accomplished in order to solve such a problem is aimed to thoroughly remove noxious contents in exhaust gas, such as carbon monoxide CO, hydrocarbons HC, nitrogen oxides NO_x or the like, by converting these into innoxious components immediately after starting up and before completion of warming up of engines and also after the warming up has been completed.

The exhaust gas purifying apparatus of the present invention comprises first and second exhaust converters arranged in sequence from an exhaust manifold towards the downstream exhaust gas flow of an engine, each having a catalytic substrate formed in a honeycomb structure wherein a plurality of cells are contiguously bored therethrough in the axial direction of the catalytic substrate, each of the cells being defined by a partition wall, and is characterized in that the catalytic substrate of said first exhaust converter has a heat capacity of not exceeding 0.5 J/K per 1 cm^3 in temperatures ranging up to a temperature at least high enough to activate a catalytic reaction, i.e., in the temperature range between room temperature and 300°C, and the catalytic substrate of said second exhaust converter has a geometric surface area of at least 25 cm^2/cm^3. Throughout this specification, the term "geometric surface area" should be understood to mean the surface area of the partition walls defining the cells, per unit volume of a catalytic substrate.

Further, in the exhaust gas purifying apparatus according to the present invention, it is desired that the partition walls defining the cells of the catalytic substrate in the first exhaust converter are at most 0.20 mm thick and those in the second exhaust converter are at most 0.15 mm thick.

Furthermore, both in the first and second exhaust converters of the exhaust gas purifying apparatus according to the present invention, the number of the cells in the catalytic substrate is preferably at least 50 per 1 cm^2 of a plane perpendicular to the longitudinal axes of the cells. Hereinafter, the number of cells per 1 cm^2 of a plane perpendicular to the longitudinal axes of the cells in the catalytic substrate is referred to as "cell density".

Furthermore, the exhaust gas purifying apparatus according to the present invention may further comprise at least one additional exhaust converter arranged downstream the exhaust gas flow from the second exhaust converter in order to increase the exhaust gas purification efficiency.

Furthermore, in the exhaust gas purifying apparatus according to the present invention, it is preferred that at least on of the first and second exhaust converters has a catalytic substrat made of a c ramic.

Furth rmore, the exhaust gas purifying apparatus according to the present inv ntion is preferably provided with an air introducing d vice which can feed air at an arbitrary feed rate into the gas flow b tw en the exhaust manifold and the first exhaust converter.

Furthermore, in the exhaust gas purifying apparatus according to the present invention, it is preferred that a gas detector is arranged between the exhaust manifold and the first exhaust converter, to d t ct th condition of the exhaust gas composition and output a signal for thereby controlling the fuel combusting condition.

Furthermore, in the exhaust gas purifying apparatus according to the present invention, it is preferred that a gas detector is arranged between the exhaust manifold and the first exhaust converter, to detect the condition of the exhaust gas composition and output a signal for thereby controlling the fuel combusting condition, and an air introducing device is provided to feed air at an arbitrary feed rate into at least one of the gas flows between the exhaust manifold and the gas detector and between the gas detector and the first exhaust converter.

Furthermore, in the exhaust gas purifying apparatus according to the present invention, it is preferred that the air introducing device can feed air at an arbitrary feed rate corresponding to the signal output from the gas detector.

Furthermore, in the exhaust gas purifying apparatus according to the present invention, the gas detector is preferably an oxygen sensor.

According to the exhaust gas purifying apparatus of the present invention, the exhaust converter system is divided into the first and second exhaust converters both comprising a honeycomb structure, the catalytic substrate of the first converter is formed to have a small heat capacity and the catalytic substrate of the second converter is formed to have a sufficiently large geometric surface area. Accordingly, engines equipped with the exhaust gas purifying apparatus according to the present invention can maintain a good exhaust gas purification efficiency both before and after completion of warming up. Therefore, the apparatus of the present invention is effective to mitigate air pollution due to noxious contents in exhaust gas.

Additionally, according to the exhaust gas purifying apparatus of the present invention, the exhaust gas purification efficiency can be further improved by arranging an air introducing device for feeding air at an arbitrary feed rate into gas flow between the exhaust manifold and the first exhaust converter.

Brief Description of the Drawing

The above and other optional, features and advantages of the present invention will become more apparent from reading the following description of the preferred embodiments taken in connection with the accompanying drawings, wherein:-

Fig. 1 is a schematic view illustrating an exhaust gas flow route in an engine wherein an embodiment of the exhaust gas purifying apparatus according to the present invention is applied.

Fig. 2 is a drive chart for determining an exhaust gas purification efficiency of an automobile, which shows a relation between driving time and vehicle speed.

Fig. 3A is an enlargement of the portion III in Fig. 2.

Fig. 3B is a characteristic chart showing relations between driving time and quantities of exhaust hydrocarbons HC within the range shown in Fig. 3A, according to Examples 1, 2 and 3 of the invention and Comparative Examples 1 and 2.

Fig. 4 is a characteristic diagram showing relations of the hydrocarbon HC purification efficiency with the heat capacity per 1 cm^3 of the catalytic substrate of the first exhaust converter in conjunction with the geometric surface area of the catalytic substrate of the second exhaust converter, in the embodiment of the exhaust gas purifying apparatus of the present invention.

Fig. 5 is a characteristic diagram showing relations of the hydrocarbon HC purification efficiency with the geometric surface area of the catalytic substrate of the second exhaust converter in conjunction with the heat capacity per 1 cm^3 of the catalytic substrate of the first exhaust converter, in the embodiment shown in Fig. 4.

Fig. 6 is a characteristic diagram showing relations of the hydrocarbon HC purification efficiency with the partition wall thickness of the catalytic substrate of the first exhaust converter in conjunction with the partition wall thickness of the catalytic substrate of the second exhaust converter, in the embodiment of the exhaust gas purifying apparatus of the present invention.

Fig. 7 is a characteristic diagram showing relations of the hydrocarbon HC purification effici ncy with the cell density of the catalytic substrate of the first exhaust converter in conjunction with the cell density of the catalytic substrate of the second exhaust converter, in the embodiment of the exhaust gas purifying apparatus of the present invention.

Fig. 8 is a schematic view illustrating an exhaust gas flow route in an engine wherein another embodiment of the exhaust gas purifying apparatus according to the present invention is applied.

Fig. 9 is a characteristic diagram showing r lations of the hydrocarbon HC purification efficiency with the heat capacity per 1 cm^3 of the catalytic substrate of th first exhaust converter in conjunction with the geometric surface area of the catalytic substrate of the second exhaust conv rter, in the other embodiment of the exhaust gas purifying apparatus of the present invention.

Fig. 10 is a characteristic diagram showing r lations of th hydrocarbon HC purification effici ncy with the partition wall thickness of the catalytic substrate of the first exhaust converter in conjunction with the partition wall thickness of the catalytic substrate of the second exhaust converter, in the other embodiment of the exhaust gas purifying apparatus of the present invention.

Fig. 11 is a characteristic diagram showing relations of the hydrocarbon HC purification efficiency with the cell density of the catalytic substrate of the first exhaust converter in conjunction with cell density of the catalytic substrate of the second exhaust converter, in the other embodiment of the exhaust gas purifying apparatus of the present invention.

Description of the Preferred Embodiments

Preferred embodiments of the present invention will be explained based on the drawings hereinbelow.

Fig. 1 shows an exhaust gas flow route in an engine wherein an embodiment of the exhaust gas purifying apparatus according to the present invention is applied.

In Fig. 1, the flow route of exhaust gas discharged from an automobile engine includes an engine body 1, an exhaust manifold 2 and an exhaust gas purifying apparatus 10.

The exhaust gas purifying apparatus 10 comprises an oxygen sensor 11, an engine control computer 12, an exhaust pipe 21, a first exhaust converter 16, an intermediate exhaust pipe 22, and a second exhaust converter 17. The oxygen sensor 11, the first exhaust converter 16 and the second exhaust converter 17 are arranged in this order toward the downstream flow of the gas collected by the exhaust manifold 2. The oxygen sensor 11 outputs a signal corresponding to the oxygen partial pressure in the exhaust gas immediately after the exhaust gas is collected by the exhaust manifold 2. The engine control computer 12 receives the signal output from the oxygen sensor 11 and determines a feed rate of fuel to be supplied to the engine. The exhaust gas collected by the exhaust manifold 2 is forwarded through the exhaust pipe 21 to the first exhaust converter 16 wherein the exhaust gas is purified. The exhaust gas which has passed through the first exhaust converter flows through the intermediate exhaust pipe 22 into the second exhaust converter 17 wherein the exhaust gas is further purified.

The oxygen sensor 11 to function as a gas detector is arranged in the exhaust pipe 21 between the exhaust manifold 2 and the first exhaust converter 16. As this sensor is employed a dual signal output type which outputs two kinds of signals, i.e., a rich signal indicating a rich mixture and a lean signal indicating a lean mixture with respect to the theoretical air/fuel mixture ratio (Ga/Gf). Alternatively, a Ga/Gf sensor of a whole region type also can be employed which outputs a signal in proportion to the oxygen partial pressure in the exhaust gas collected by the exhaust manifold 2.

The first exhaust converter 16 is preferred to comprise a catalytic substrate of a honeycomb structure made of cordierite which has a number of cells and a small capacity. Platinum Pt typical as a metallic catalyst is carried on the catalytic substrate. The heat capacity of the catalytic substrate is preferred to be at most 0.5 J/K, more preferably at most 0.4 J/K, per 1 cm^3 in the temperature range from at least room temperature to 300°C. This heat capacity can be appropriately controlled by adequately selecting the partition wall thickness of cells, cell density, porosity and the like, of the catalytic substrate. A preferable partition wall thickness of cells is at most 0.20 mm, more preferably at most 0.15 mm, and a preferable cell density is at least 50 cells/cm^2, more preferably at least 65 cells/cm^2. Alternatively, as the metallic catalyst, rhodium Rh, palladium Pd or the like also can be used in lieu of or in addition of platinum Pt.

The second exhaust converter 17 is preferred to comprise a catalytic substrate of a honeycomb structure made of cordierite which has a number of cells and a large capacity. The catalytic substrate carries platinum Pt typical as a metallic catalyst. The geometric surface area of the catalytic substrate is preferred to be at least 25 cm^2/cm^3, more preferably at least 30 cm^2/cm^3. This geometric surface area can be appropriately controlled by adequately selecting the partition wall thickness of cells and the cell density. A preferable partition wall thickness of cells is at most 0.15 mm, and a preferable cell density of the catalytic substrate is at least 50 cells/cm^2, more pref rably at least 65 cells/cm^2. Alternatively, as th metallic catalyst, rhodium Rh, palladium Pd or the like also can be used in lieu of or in addition of platinum Pt.

The proc ss of purifying the exhaust gas discharged from the engine body 1 will be explained hereinbelow.

The xhaust gas discharged from the engine body 1 is collected by the exhaust manifold 2 and transferred into the exhaust pipe 21. The oxygen s nsor 11 detects the oxygen partial pr ssure in the exhaust gas in the exhaust pip 21 and gives a rich signal or a lean signal to the engin control computer 12. According to the

output signal, the engine control computer 12 regulates the feed rate of the fuel s as to achieve an optimal air/fuel mixture ratio (Ga/Gf).

Since the first exhaust convert r 16 has a small capacity and comprises a catalytic substrate having a small heat capacity, its temperature is rapidly rais d by exhaust gas passing therethrough and the catalyst is activated even when the engine is in the condition of immediately after starting up and before completion of warming up. Accordingly, a good exhaust gas purification efficiency can be maintained even during starting up the engine. The exhaust gas purified in the first exhaust converter 16 flows through the intermediate exhaust pipe 22 into the second exhaust converter 17.

The second exhaust converter 17, since it has a large capacity and comprises a catalytic substrate having a large geometric surface area, can efficiently purify carbon monoxide CO, hydrocarbons HC and nitrogen oxides NO_x which still remain in the exhaust gas as being beyond capacity of the first exhaust converter.

In the above-described embodiment of the present invention, a good exhaust gas purification efficiency can be maintained, no matter whether the warming up of the engine body 1 immediately after starting up has been completed or not.

In the next place, experimental data will be explained in reference to Figs. 2~7.

In Experiments 1~4, the quantity and purification efficiency of exhaust hydrocarbons HC were determined when a 2,000 cc automobile was driven according to the drive pattern shown in Fig. 2. The catalytic substrates of the first and second exhaust converters were both made of cordierite and had constant capacities of 700 cm^3 and 1700 cm^3, respectively. The employed oxygen sensor could output a rich signal or a lean signal corresponding to the oxygen partial pressure in the exhaust gas.

Further, in these experiments, the metallic catalysts carried by the substrates were equalized in quantity among all the first exhaust converters and also among all the second exhaust converters, respectively.

(Experiment 1)

Fig. 3A is an enlargement of the portion circled by the chain line III in the drive chart shown in Fig. 2. As shown in Fig. 3A, when an automobile drives according to the drive pattern shown in Fig. 2, about 80% in quantity of the total exhaust hydrocarbons HC is discharged within about 140 seconds after starting up the engine. Therefore, the performance of the exhaust gas purifying apparatus depends largely upon the hydrocarbon HC purification efficiency in this period of time.

Fig. 3B shows the result in that the quantity of the exhaust hydrocarbons HC was determined under the condition shown in Table 1, within the range shown in Fig. 3A. The graphs 41, 42, 43 and 44 show the results of measurements in Example 1, Example 2, Comparative Example 1 and Comparative Example 2, respectively.

Table 1

Particular	Heat Capacity/cm^3 of First Exhaust Converter (J/K)	Geometric Surface Area of Second Exhaust Converter (cm^2/cm^3)	Oxygen Sensor	Air Introducing Device
Example 1	0.5	25	Rich and lean dual signals output type	Nil
Example 2	0.28	25	- ditto -	Nil
Example 3	0.5	25	All region Ga/Gf type, air excess ratio: 1.05±0.05	Attached
Comparative Example 1	0.7	20	Rich and lean dual signals output type	Nil
Comparative Example 2	0.7	25	- ditto -	Nil

It is understood that in the results of measurement in Examples 1 and 2, respectively shown by the graphs 41 and 42, the quantities of the exhaust hydrocarbons HC are fairly small as compared with Comparative Examples 1 and 2, respectively shown by the graphs 43 and 44.

In the und r-explained Experiments 2 - 4, a dual signal output typ oxygen sensor which outputs a rich signal or a lean signal corresponding to the oxygen partial pressure in xhaust gas was used. Further, with respect to the first exhaust conv rter, th heat capacity per 1 cm^3 of the catalytic substrate was repr s nted by the maximal valu in the range from room t mperature to 300°C.

(Experiment 2)

With changing the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter and the geometric surface area of the catalytic substrate in the second exhaust converter, changes of the hydrocarbon HC purification efficiency were measured. With respect to the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter, a desired value was obtained by changing the cell density in the range from 65 cells/cm^2 to 200 cells/cm^2 and the porosity in the range from 7% to 28% while the partition wall thickness was kept constant, in the catalytic substrate. Alternatively, with respect to the geometric surface area of the catalytic substrate in the second exhaust converter, a desired value was obtained by changing the cell density while the partition wall thickness was kept constant at 0.13 mm. The results of the experiments are shown in Fig. 4.

In Fig. 4, it is understood that the hydrocarbon HC purification efficiencies are extremely high in the range surrounded with the dotted line 20 wherein the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter is 0.5 J/K or less and the geometric surface area of the catalytic substrate in the second exhaust converter is 25 cm^2/cm^3 or more, so that converters comprising catalytic substrates within the above range are preferred for providing good exhaust gas purifying apparatuses. Moreover, further better exhaust gas purifying apparatuses were obtained in the range wherein the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter was 0.4 J/K or less and the geometric surface area of the catalytic substrate in the second exhaust converter was 30 cm^2/cm^3 or more.

In these experiments, only metallic catalysts were used and the heat capacity per 1 cm^3 of the substrate with the catalysts was 1.5 times that of the substrate alone. Further, changing the catalyst carrying condition, a catalytic substrate with the catalysts which had a heat capacity per unit volume of the substrate of 1.3 times that of the substrate alone was prepared. This catalytic substrate was tested and the same result was obtained.

Fig. 5 is a diagram showing plots of the hydrocarbon HC purification efficiency when abscissae of the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter were replaced by abscissae of the geometric surface area of the catalytic substrate in the second exhaust converter.

In Fig. 5, it is understood that the hydrocarbon HC purification efficiencies are extremely high in the range surrounded with the dotted line 30 wherein the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter is 0.5 J/K or less and the geometric surface area of the catalytic substrate in the second exhaust converter is 25 cm^2/cm^3 or more, so that converters comprising catalytic substrates within the above range are preferred for providing good exhaust gas purifying apparatuses.

Then, since the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter and the geometric surface area of the catalytic substrate in the second exhaust converter also depend respectively upon the partition wall thickness and the cell density, the following experiments, Experiments 3 and 4, were conducted with respect to the change of the hydrocarbon HC purification efficiency with changing partition wall thickness and cell density of the catalytic substrates of the first and second exhaust converters.

(Experiment 3)

Fig. 6 is a diagram showing a result of an experiment wherein changes of the hydrocarbon HC purification efficiency were measured with changing partition wall thicknesses of the catalytic substrates in the first and second exhaust converters, respectively. In both the catalytic substrates of the first and second exhaust converters, only the partition wall thickness was changed while the cell density was kept constant at 65 cells/cm^2.

In Fig. 6, it is understood that the hydrocarbon HC purification efficiencies are extremely high in the range surrounded with the dotted line 50 wherein the partition wall thickness of the catalytic substrate in the first exhaust converter is 0.20 mm or less and the partition wall thickness of the catalytic substrate in the second exhaust converter is 0.15 mm or less, so that converters comprising catalytic substrates within the above range are preferred for providing good exhaust gas purifying apparatuses. Moreover, further better xhaust gas purifying apparatuses were obtained in the range wherein the partition wall thickness of th catalytic substrate in the first exhaust converter was 0.15 mm or less.

(Exp riment 4)

Fig. 7 is a characteristic diagram showing a result of an experiment wherein changes of the hydrocarbon HC purification efficiency wer m asured with changing cell densities of the catalytic substrates in the first and second exhaust converters, respectively. In the catalytic substrates of the first and second xhaust converters, only the cell density was changed while the partition wall thicknesses were kept constant at 0.15 mm and 0.10 mm, respectively.

In Fig. 7, it is understood that the hydrocarbon HC purification efficiencies are extremely high in the range surrounded with the dotted line 60 wherein the cell densities of the catalytic substrates in the first and second exhaust converters are both 50 cells/cm^2 or more, so that converters comprising catalytic substrates within the above range are preferred for providing good exhaust gas purifying apparatuses. Moreover, further better exhaust gas purifying apparatuses were obtained in the range wherein the cell density of the catalytic substrates in the first and second exhaust converters was 65 cells/cm^2 or more.

In Figs. 3B, 4, 5, 6 and 7 which show the experiment results of the above Experiments 1 - 4, only the hydrocarbon HC purification efficiencies were shown. However, with respect to carbon monoxide CO and nitrogen oxides NO_x, substantially the same results were also obtained in the ranges wherein the exhaust gas purifying apparatus showed a good exhaust gas purification efficiency with respect to hydrocarbons.

In this embodiment, the oxygen sensor 11 is arranged between the exhaust manifold 2 and the first exhaust converter 16, which functions as a gas detector and outputs a signal corresponding to the oxygen partial pressure in the exhaust gas and thus fuel is supplied at an optimal feed rate by means of the engine control computer 12. However, in this invention, another control system may be adopted to omit such a gas detector, in which fuel is supplied at an optimal feed rate, for example, by computing the intake of air from the number of rotations of the engine and the pressure of air in the intake manifold.

Fig. 8 shows an exhaust gas flow route in an engine wherein another embodiment of the exhaust gas purifying apparatus according to the present invention is applied.

In this embodiment, a secondary air introducing inlet 15, as an air introducing device, is arranged between the oxygen sensor 11 and the first exhaust converter 16, through which secondary air is fed into exhaust gas flow in an exhaust pipe 21. Namely, the secondary air is supplied from a pneumatic pump 13 i.e. a supply source through the secondary air introducing inlet 15 into the exhaust pipe 21, at a feed rate being regulated by a pneumatic valve 14. The oxygen sensor 11, the secondary air introducing inlet 15, the first exhaust converter 16 and the second exhaust converter 17 are arranged in this order toward downstream flow of the gas collected by the exhaust manifold 2.

As the oxygen sensor 11, a whole region type Ga/Gf sensor is employed which outputs a signal in proportion to the oxygen partial pressure in the exhaust gas. An engine control computer 12 receives the output signal from the oxygen sensor 11 and determines optimal feed rates of fuel and secondary air. As the oxygen sensor 11 also can be employed a dual signal output type sensor which outputs a rich or lean signal corresponding to the oxygen partial pressure of the exhaust gas. The secondary air introducing inlet 15 may be arranged in either or both of between the exhaust manifold 2 and the oxygen sensor 11 and between the oxygen sensor 11 and the first exhaust converter 16.

The pneumatic pump 13 is driven by power of an output shaft not shown of the engine body 1. According to this manner, the pneumatic pump 13 is driven always during operation of the engine. Therefore, in the case where an excessive oxygen exists in the exhaust gas in the exhaust pipe 21, the pneumatic valve 14 constricts to reduce the feed rate of air, giving an excessive load back to the pneumatic pump 13 which may be prone to damage. In order to avoid the damage and prolong the life of the pneumatic pump 13, use can be made of an electric motor which can drive only for feeding air into the exhaust gas in the exhaust pipe 21.

The pneumatic valve 14 feeds the secondary air into the exhaust gas in the exhaust pipe 21, regulating the feed rate at an optimal value according to the control signal output from the engine control computer 12. Then, in order to optimize the exhaust gas purification efficiency, it is desired that the air excess ratio of the exhaust gas downstream the secondary air introducing inlet 15 is made to be 1.05 ± 0.05.

A process of purifying the exhaust gas discharged from the engine body 1 by the secondary air will be explained hereinbelow.

Th exhaust gas discharged from the engine body 1 is collected by the exhaust manifold 2 and transferred into the exhaust pipe 21. The oxygen sensor 11 detects the oxygen partial pressure of the exhaust gas in the exhaust pipe 21 and gives a signal output corresponding to the oxygen partial pressure to the engine control computer 12. According to this output signal, the engine control computer 12 determines a feed rate of fuel and gives an on/off signal to th pneumatic valve 14. The exhaust gas mixed with the optimized quantity of the secondary air flows into the first exhaust converter 16. Then, in order that the nitrogen oxide NO_x purification efficiency may not be deteriorated, it is recommended that the secondary air is fed only for a certain

period of time, for example, 10 to 200 seconds, immediately after starting up the engine wh n large quantities of carbon monoxide CO and hydrocarbons HC and a small quantity of nitrogen oxides NO_x are exhausted.

In this mbodim nt wherein the secondary air introducing inlet 15 for f ding secondary air into the exhaust pipe 21 is arrang d b tween the oxygen sensor 11 and the first exhaust converter 16, a good exhaust gas purification efficiency can be maintained, no matter whether warming up of the engine body 1 immediately after starting up has been completed or not.

In the next place, experimental data are shown in Figs. 2, 3, and 9~11.

In Experiments 5~8, the quantity and purification efficiency of exhaust hydrocarbons HC were determined when a 2,000 cc automobile was driven according to the drive pattern shown in Fig. 2. The catalytic substrates of the first and second exhaust converters were both made of cordierite and had constant capacities of 700 cm^3 and 1700 cm^3, respectively. The secondary air was fed into the exhaust pipe only for 120 seconds after starting up the engine. As an oxygen sensor, a whole region type Ga/Gf sensor was employed. The air excess ratio in exhaust gas at the downstream flow from the secondary air introducing inlet was 1.05 ± 0.05.

Further, in these experiments, the metallic catalysts carried by the substrates were equalized in quantity among all the first exhaust converters and also among all the second exhaust converters, respectively.

(Experiment 5)

The graph 45 shown in Fig. 3B is a plot of the quantity of the hydrocarbon HC exhaust determined under the condition shown in Table 1, Example 3, within the range shown in Fig. 3A. It is understood that the graph 45 of Example 3 shows a quantity of the exhaust hydrocarbons HC lower than those of other examples, Examples 1 and 2 and Comparative Examples 1 and 2.

(Experiment 6)

With changing the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter and the geometric surface area of the catalytic substrate in the second exhaust converter, changes of the hydrocarbon HC purification efficiency were measured. With respect to the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter, a desired value was obtained by changing the cell density in the range from 65 cells/cm^2 to 200 cells/cm^2 and the porosity in the range from 7% to 28% while the partition wall thickness was kept constant, in the catalytic substrate. Alternatively, with respect to the geometric surface area of the catalytic substrate in the second exhaust converter, a desired value was obtained by changing the cell density while the partition wall thickness was kept constant at 0.13 mm. The results of the experiments are shown in Fig. 9.

In Fig. 9, it is understood that the hydrocarbon HC purification efficiencies are extremely high in the range surrounded with the dotted line 70 wherein the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter is 0.6 J/K or less and the geometric surface area of the catalytic substrate in the second exhaust converter is 25 cm^2/cm^3 or more, so that converters comprising catalytic substrates within the above range are preferred for providing good exhaust gas purifying apparatuses.

In this experiment, metallic catalysts were used and the heat capacity per unit volume of the substrate with the catalysts was 1.5 times that of the substrate alone. Further, changing the catalyst carrying condition, a catalytic substrate with the catalysts which had a heat capacity per unit volume of the substrate of 1.3 times that of the substrate alone was prepared. This catalytic substrate was tested and the same result was obtained.

Moreover, further better exhaust gas purifying apparatuses were obtained in the range wherein the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter was 0.4 J/K or less and the geometric surface area of the catalytic substrate in the second exhaust converter was 30 cm^2/cm^3 or more.

Then, since the heat capacity per 1 cm^3 of the catalytic substrate in the first exhaust converter and the geometric surface area of the catalytic substrate in the second exhaust converter also depend respectively upon the partition wall thickness and the cell density, the following experiments, Experiments 7 and 8, were conducted with respect to the change of the hydrocarbon HC purification efficiency with changing partition wall thickness and cell density of the catalytic substrates of the first and second exhaust converters.

(Experiment 7)

Fig. 10 is a diagram showing a result of an experiment wherein changes of the hydrocarbon HC purification efficiency were measured with changing partition wall thicknesses of the catalytic substrates in the first and second exhaust convert rs, respectively. In both the catalytic substrates of the first and second exhaust converters, only the partition wall thickness was changed while the cell density was k pt constant at 65 cells/cm^2.

In Fig. 10, it is understood that the hydrocarbon HC purification efficiencies are extremely high in the range surrounded with th dotted line 80 wherein the partition wall thickness of the catalytic substrate in the first exhaust converter is 0.20 mm or less and the partition wall thickness of the catalytic substrate in the second exhaust converter is 0.15 mm or less, so that conv rters comprising catalytic substrates within the above range are preferred for providing good exhaust gas purifying apparatuses. Moreover, further better exhaust gas purifying apparatuses were obtained in the range wherein the partition wall thickness of the catalytic substrate in the first exhaust converter was 0.15 mm or less.

(Experiment 8)

Fig. 11 is a characteristic diagram showing a result of an experiment wherein changes of the hydrocarbon HC purification efficiency were measured with changing cell densities of the catalytic substrates in the first and second exhaust converters, respectively. In the catalytic substrates of the first and second exhaust converters, only the cell density was changed while the partition wall thicknesses were kept constant at 0.15 mm and 0.10 mm, respectively.

In Fig. 11, it is understood that the hydrocarbon HC purification efficiencies are extremely high in the range surrounded with the dotted line 90 wherein the cell densities of the catalytic substrates in the first and second exhaust converters are both 50 cells/cm^2 or more, so that converters comprising catalytic substrates within the above range are preferred for providing good exhaust gas purifying apparatuses. Moreover, further better exhaust gas purifying apparatuses were obtained in the range wherein the cell density of the catalytic substrates in the first and second exhaust converters was 65 cells/cm^2 or more.

In Figs. 3B, 9, 10 and 11 which show the experiment results of the above Experiments 5--8, only the hydrocarbon HC purification efficiencies were shown. However, with respect to carbon monoxide CO and nitrogen oxides NO_x, substantially the same results were also obtained in the ranges wherein the exhaust gas purifying apparatus showed a good exhaust gas purification efficiency with respect to hydrocarbons.

In this embodiment, the oxygen sensor 11 outputs a signal corresponding to the oxygen partial pressure of the exhaust gas and gives to the engine control computer 12 which thereby regulates the feed rate of secondary air to be fed into the exhaust pipe 21. However, in this invention, it is possible to regulate arbitrarily the feed rate of secondary air to be fed into the exhaust gas without using the oxygen sensor or without regard to the output signals of the oxygen sensor.

Further in this embodiment, the secondary air introducing inlet 15 was arranged between the oxygen sensor 11 and the first exhaust converter 16. However, in the present invention, the secondary air introducing inlet, as an air introducing device, may be arranged anywhere between the exhaust manifold and the first exhaust converter. Thus, it can be arranged in either or both of between the oxygen sensor i.e. a gas detector and the first exhaust converter, or between exhaust manifold outlet and the oxygen sensor.

Furthermore, this embodiment, since it requires a pneumatic pump, pneumatic valve, secondary air introducing inlet or the like, may be complicated from the structural point of view and expensive in manufacturing cost. However, it is much advantageous in that a high purification efficiency can be obtained as is clear from the above experimental results.

As explained above, in the embodiments of the present invention, further one exhaust converter or more can be arranged downstream the exhaust gas flow from the second exhaust converter in order to increase the exhaust purification efficiency. Additionally, though in the above embodiments the catalytic substrates of both the first and second exhaust converters were formed from cordierite, only either one of the first and second exhaust converters may comprise a catalytic substrate formed from a ceramic such as cordierite.

Further, in the above embodiments of the present invention, though an oxygen sensor was used as a gas detector, other types of gas detectors, such as hydrocarbons HC detectors or nitrogen oxides NO_x detectors, also can be used in lieu of the oxygen sensor, according to the present invention.

Claims

1. An exhaust gas purifying apparatus comprising first and second exhaust converters arranged in sequence from an xhaust manifold towards downstream exhaust gas flow of an engine, each having a catalytic substrate formed in a honeycomb structure wherein a plurality of exhaust flow passages are contiguously extending therethrough in the axial direction of the catalytic substrate and each defined by a partition wall, the catalytic substrate of said first exhaust converter having a heat capacity of not exceeding 0.5 J/K per 1 cm^3 in temperatures ranging from room temperature up to 300°C, and the catalytic substrate of said second exhaust converter having a geometric surface area of at least 25 cm^2/cm^3.

2. The apparatus according to claim 1, wher in the partition walls defining said exhaust flow passages of the catalytic substrate in said first exhaust converter are at most 0.20 mm thick and those in said second xhaust converter ar at most 0.15 mm thick.

3. The apparatus according to claim 1 or 2, wherein both in said first and second exhaust converters the number of said exhaust flow passages in the catalytic substrate is at least 50 per 1 cm^2 of a plane perpendicular to the longitudinal axes of said exhaust flow passages.

4. The apparatus according to claim 1, 2 or 3, further comprising at least one additional exhaust converter arranged downstream exhaust gas flow from said second exhaust converter.

5. The apparatus according to claim 1, 2, 3 or 4, wherein the catalytic substrate of at least one of said first and second exhaust converters is made of a ceramic.

6. The apparatus according to claim 1, 2, 3, 4 or 5, further comprising an air introducing device to feed air at an arbitrary feed rate into gas flow between said exhaust manifold and said first exhaust converter.

7. The apparatus according to claim 1, 2, 3, 4 or 5, further comprising a gas detector arranged between said exhaust manifold and said first exhaust converter, to detect conditions of exhaust gas composition and output a signal for thereby controlling a fuel combusting condition.

8. The apparatus according to claim 7, further comprising an air introducing device to feed air at an arbitrary feed rate into at least one of the gas flows between said exhaust manifold and said gas detector and between said gas detector and said first exhaust converter.

9. The apparatus according to claim 8, wherein said air introducing device feeds air at an arbitrary feed rate corresponding to the signal output from said gas detector.

10. The apparatus according to claim 7, 8 or 9, wherein said gas detector is an oxygen sensor.

FIG_1

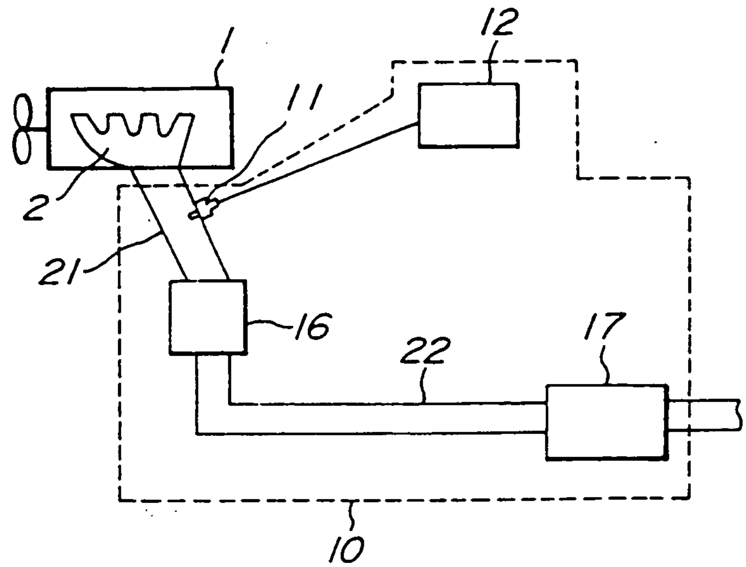


FIG_2

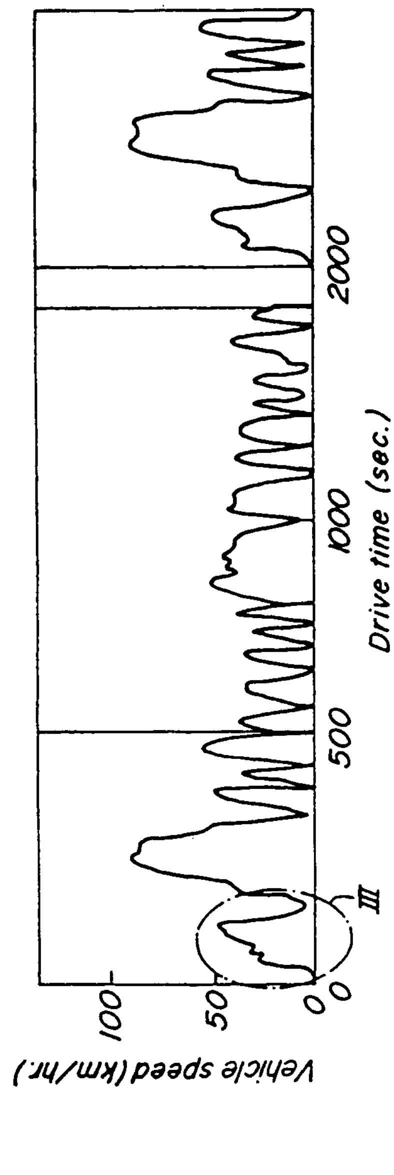


FIG_3A

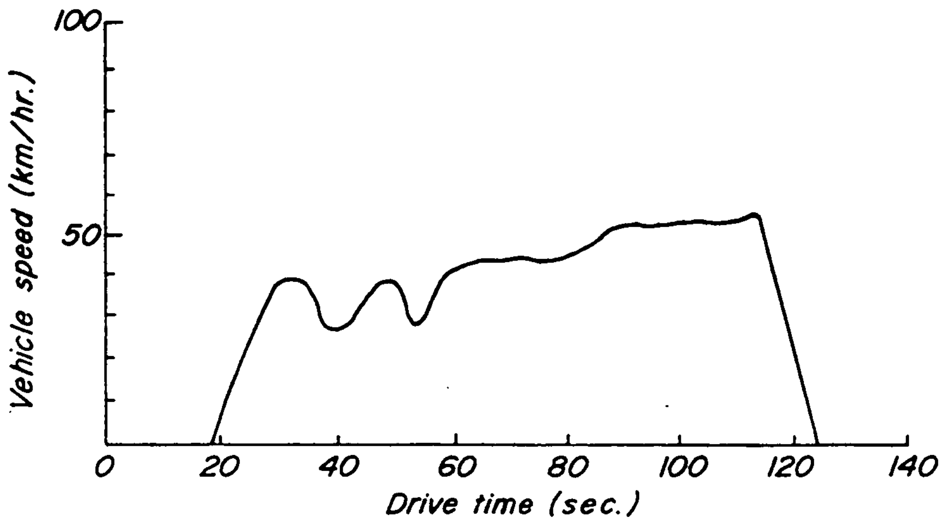

100
50
Vehicle speed (km/hr.)
0
20
40
60
80
100
120
140
Drive time (sec.)

FIG_3B

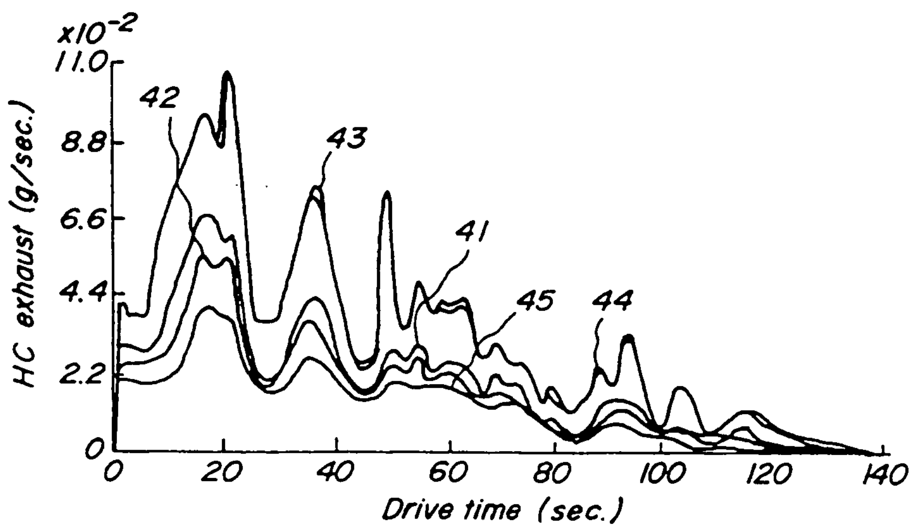

x10^-2
11.0
8.8
6.6
4.4
2.2
0
HC exhaust (g/sec.)
42
43
41
45
44
0
20
40
60
80
100
120
140
Drive time (sec.)

FIG_4

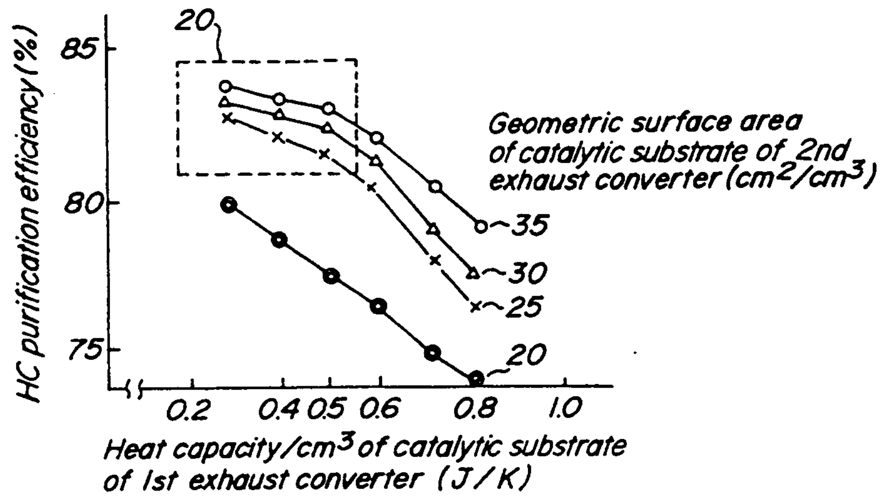

HC purification efficiency (%)
85
80
75
20
Geometric surface area of catalytic substrate of 2nd exhaust converter (cm^2/cm^3)
35
30
25
20
0.2
0.4
0.5
0.6
0.8
1.0
Heat capacity/cm^3 of catalytic substrate of 1st exhaust converter (J/K)

FIG_5

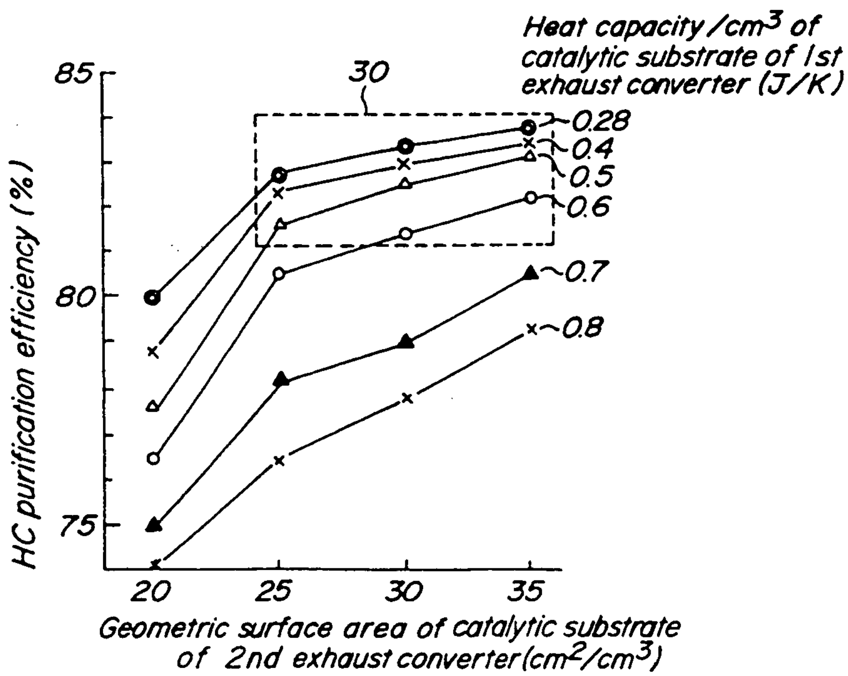

Heat capacity/cm^3 of catalytic substrate of 1st exhaust converter (J/K)
HC purification efficiency (%)
85
80
75
30
0.28
0.4
0.5
0.6
0.7
0.8
20
25
30
35
Geometric surface area of catalytic substrate of 2nd exhaust converter (cm^2/cm^3)

FIG_6

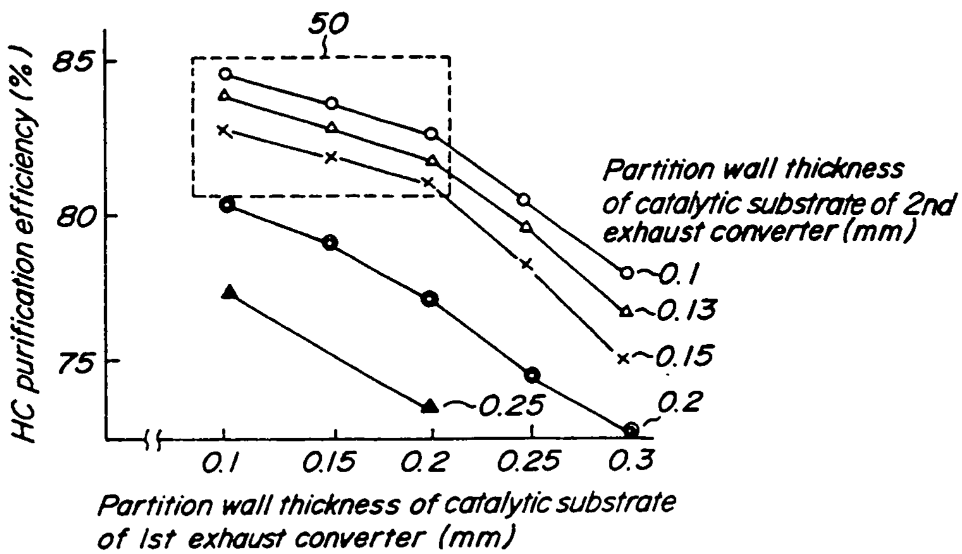

50
85
80
75
HC purification efficiency (%)
Partition wall thickness
of catalytic substrate of 2nd
exhaust converter (mm)
0.1
0.13
0.15
0.2
0.25
0.1
0.15
0.2
0.25
0.3
Partition wall thickness of catalytic substrate
of 1st exhaust converter (mm)

FIG_7

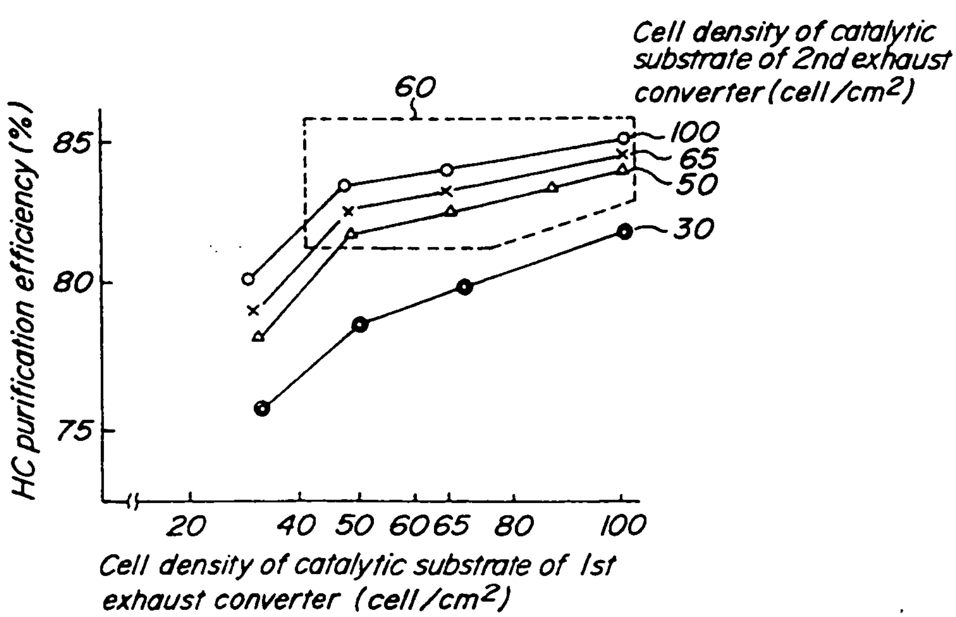

Cell density of catalytic
substrate of 2nd exhaust
converter (cell/cm2)
60
85
80
75
HC purification efficiency (%)
100
65
50
30
20
40
50
60
65
80
100
Cell density of catalytic substrate of 1st
exhaust converter (cell/cm2)

FIG_8

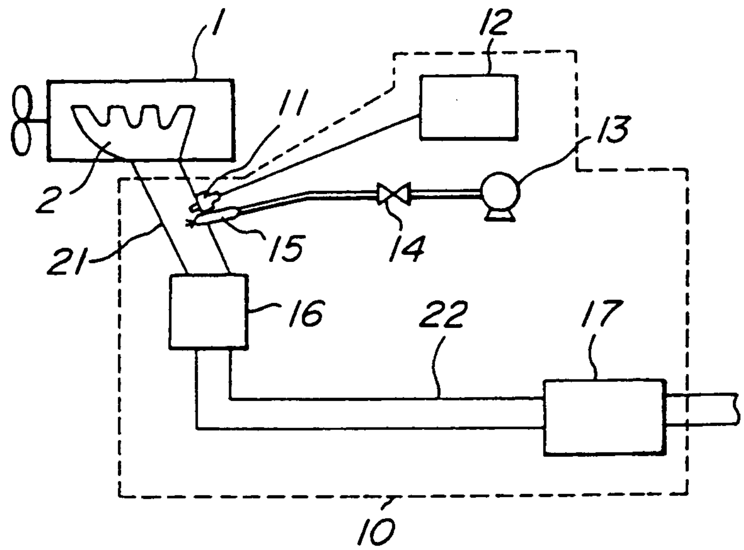

1
12
11
13
2
21
15
14
16
22
17
10

FIG_9

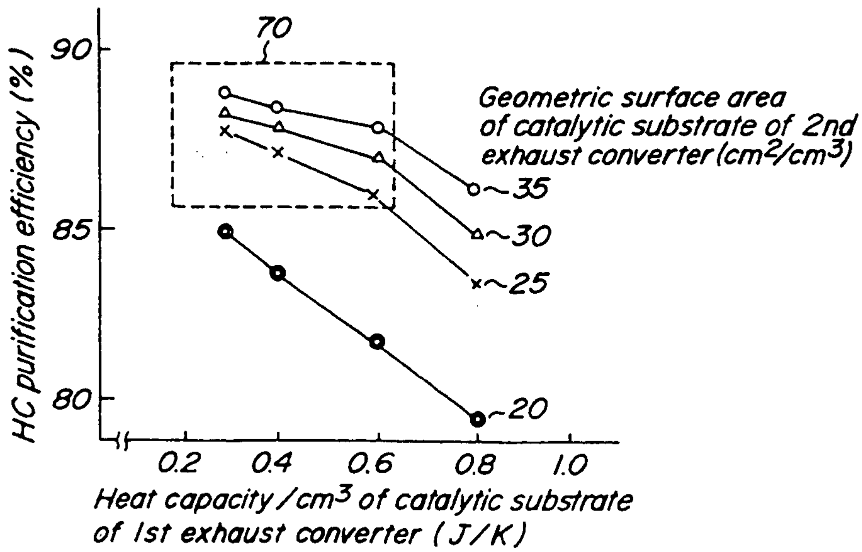

70
90
85
80
HC purification efficiency (%)
Geometric surface area
of catalytic substrate of 2nd
exhaust converter (cm2/cm3)
~35
~30
~25
~20
0.2
0.4
0.6
0.8
1.0
Heat capacity / cm3 of catalytic substrate
of 1st exhaust converter (J/K)

FIG_10

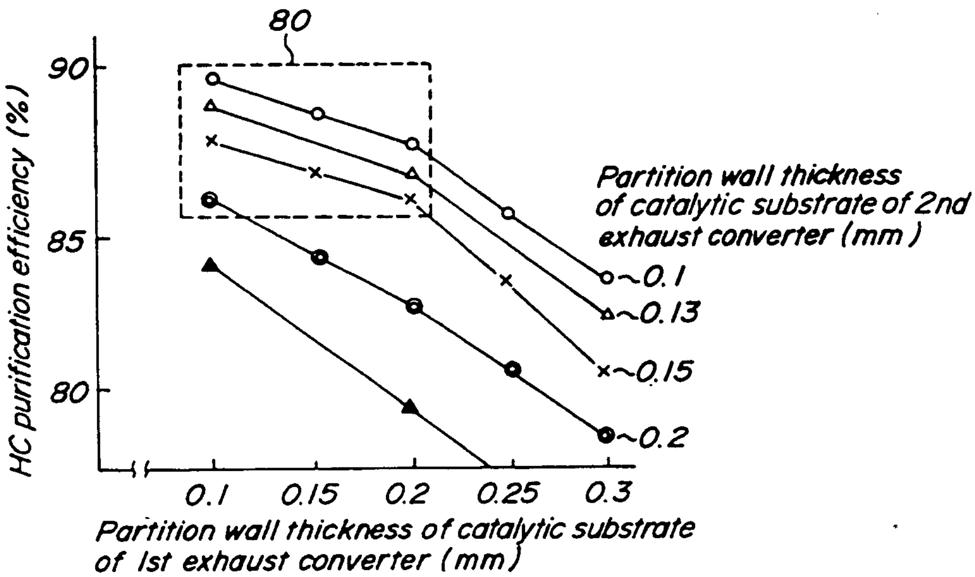
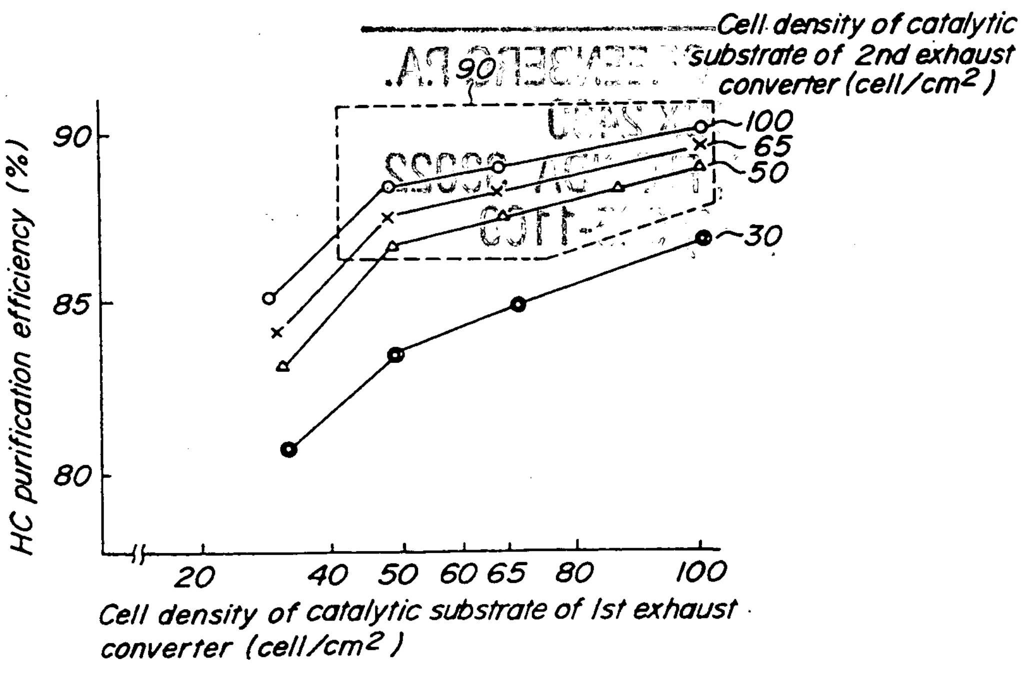

80
90
85
80
HC purification efficiency (%)
Partition wall thickness
of catalytic substrate of 2nd
exhaust converter (mm)
0.1
0.13
0.15
0.2
0.1 0.15 0.2 0.25 0.3
Partition wall thickness of catalytic substrate
of 1st exhaust converter (mm)

FIG_11


Cell density of catalytic
substrate of 2nd exhaust
converter (cell/cm2)
90
100
65
50
30
90
85
80
HC purification efficiency (%)
20 40 50 60 65 80 100
Cell density of catalytic substrate of 1st exhaust
converter (cell/cm2)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 30 2180

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	FR-A-2 450 946 (PEUGEOT) * page 4, line 8 - line 30; figure *	1,5-7,10	F01N3/28 F01N9/00 F01N3/22
A	GB-A-1 371 941 (UNIVERSAL OIL PRODUCTS) * page 1, line 58 - page 2, line 116; figure 1 *	1	
A	EP-A-0 283 220 (NGK INSULATORS) * page 5; figure 4 *	1-3	
A	PATENT ABSTRACTS OF JAPAN vol. 15, no. 473 (M-1185) 29 November 1991 & JP-A-03 202 613 (KOMATSU LTD) 4 September 1991 * abstract *	1,5	
A	FR-A-2 367 188 (ENGELHARD)		
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)
			F01N

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	24 June 1994	Sideris, M

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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